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University of Colorado

Laboratory For Atmospheric And Space Physics



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U N I V E R S I T Y O F C O L O R A D O

LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS

A N N U A L R E P O R T

1972-1973

The Laboratory for Atmospheric and Space Physics (LASP) is an institute of the Graduate School of the University of Colorado that provides an opportunity for students and faculty to participate in the national space program. In particular, students from the departments of Physics and Astrophysics, Astro-Geophysics, and Aerospace Engineering Sciences can pursue their research interests under the auspices of the Laboratory. Members of LASP collaborate on space experiments with other members of the University faculty and staff, usually in the departments of Physics and Astrophysics, Astro-Geophysics, Aerospace Engineering Sciences and the Joint Institute for Laboratory Astrophysics, as well as other scientific institutions in Boulder. LASP has also actively conducted experimental and theoretical work with other universities in the United States and abroad. In the past year work was underway with France, Germany and the Soviet Union.

The research program of LASP is centered on solar physics, planetary atmospheres and space astronomy. In each of these areas of space research, the approach to the unsolved problems involves experimental techniques, theoretical analysis and the use of computers to analyze the

data from space experiments. The LASP research program is characterized by each activity interacting with the other activities in the Laboratory. For example, a radiative transfer problem in a planetary atmosphere has its analog in the formation of a spectral line in a stellar atmosphere. The detailed study of the sun serves as a model for a particular class of stars. In the experimental program the unifying technique is ultraviolet spectroscopy. LASP has participated in ultraviolet spectrometer experiments from rockets, satellites and planetary probes of the earth, the planets, the sun, the stars and the interstellar medium. Optical design, electronic development and calibration techniques developed for one program find their immediate application to another. In addition, there is a special interaction that is part of LASP's activities; the direct cause and effect between events occurring on the sun with a subsequent reaction by the Earth's atmosphere, the solar-terrestrial interaction.

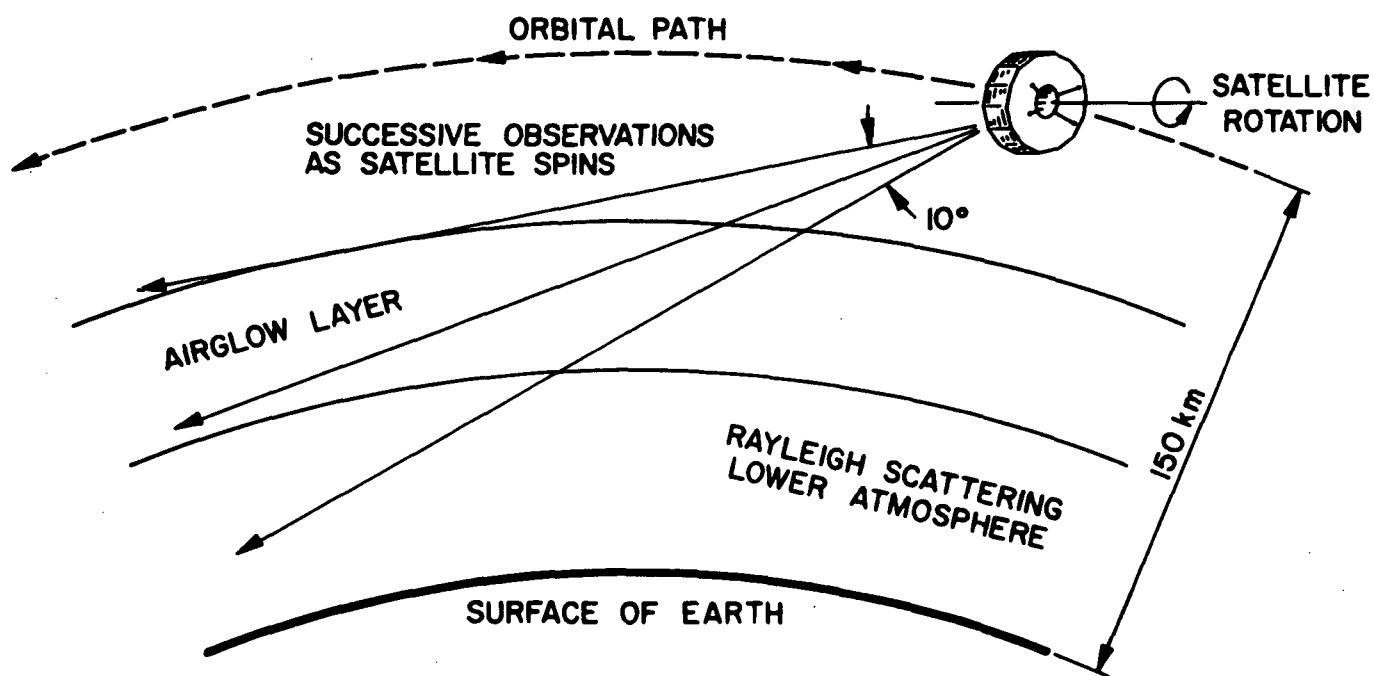
The following pages report on current and future LASP activities in the major fields of research showing their interrelation of the LASP programs.

Planetary Atmospheres

The Earth

The Atmospheric Explorer C (AE-C) spacecraft, to be launched on November 1, 1973, will carry the University of Colorado's ultraviolet Nitric Oxide (UVNO) instrument. This instrument, in the tradition of LASP ultraviolet instruments, has been designed, built and tested at LASP, and is currently undergoing final testing, calibration and integration with the spacecraft. It is a fixed-grating Ebert-Fastie spectrometer, with two exit slits positioned to permit light in 15 Å bands centered at 2150 Å and 2190 Å to pass through to two photomultiplier tubes. Output from the photomultiplier tubes is amplified and processed by pulse-counting electronics which measure the intensity of the light falling on the photomultiplier detector heads at intervals of 20 milliseconds.

The spacecraft will normally be spinning at a rate of 4 rpm, and the UVNO instrument is mounted to look outwards, perpendicular to the spin axis, which is itself perpendicular to the orbit plane as shown in the figure. Thus, every 15 seconds the instrument will successively scan the sky above the spacecraft, the limb of the Earth ahead, the lower atmosphere of the Earth below, and finally the limb of the Earth behind and the sky above again. As it scans downwards



through the atmosphere near the limb ahead, the intensity of sunlight scattered from nitric oxide molecules in the (1,0) band of the Gamma band system will be recorded together with a contamination due to Rayleigh scattering of sunlight at the same wavelength ($\sim 2150 \text{ \AA}$). The second channel will record only Rayleigh scattered light and so will provide a correction for this contamination. From the intensity of the light scattered by nitric oxide molecules and measured by the UVNO instrument, the abundance of NO molecules along the line of sight is readily determined. From these abundances the distribution of NO molecules with altitude and with position along the spacecraft's track can also be determined.

The UVNO data will be reduced and analyzed on two different computer systems. The first, the AE-C-dedicated XDS Sigma-9 computer at Goddard Space Flight Center, Greenbelt, Maryland, will contain programs written at LASP which will reduce and analyze "normal" data in a routine way. This computer will also contain stored results from the UVNO and the other 13 experiments on board AE-C, and will serve as the primary means of communication of data and results between the 14 investigators. The second

computer system is LASP's DEC PDP-8 minicomputer system which provides a flexible and powerful capability for interactive data analysis. This will be used to examine and analyze "anomalous" data, which may be expected to arise because of disturbed atmospheric conditions, or simply because of our incomplete understanding of the processes controlling the distribution of nitric oxide in the upper atmosphere.

AE-C is a "problem-solving" satellite, and apart from the exploration of the distribution and variations of nitric oxide, the UVNO experimental effort will be directed towards the correlation of many of the atmospheric quantities measured by the 14 AE experiments, and towards the development of a comprehensive explanation of many atmospheric processes and events, which earlier investigations have shown to be important, but which are as yet not understood. It will be kept in operation at least until its successor, AE-D, is launched in the spring of 1975. Dr. A. I. Stewart will be in charge of the program, the scientific coordination, and the data analysis, in association with Dr. C. A. Barth.

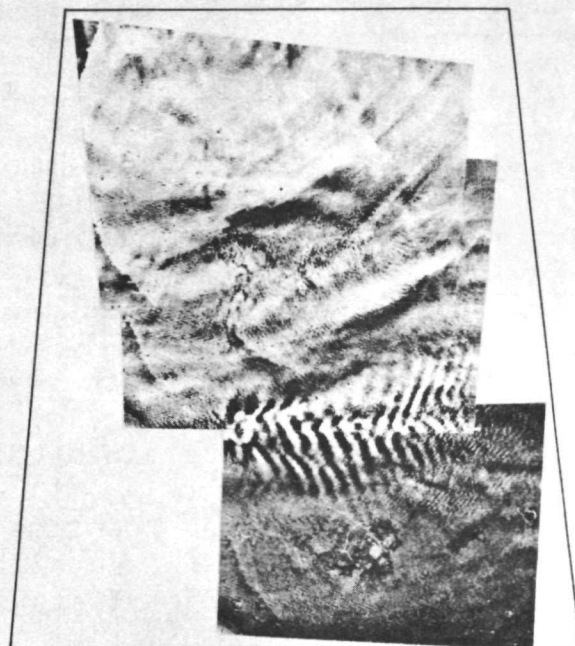
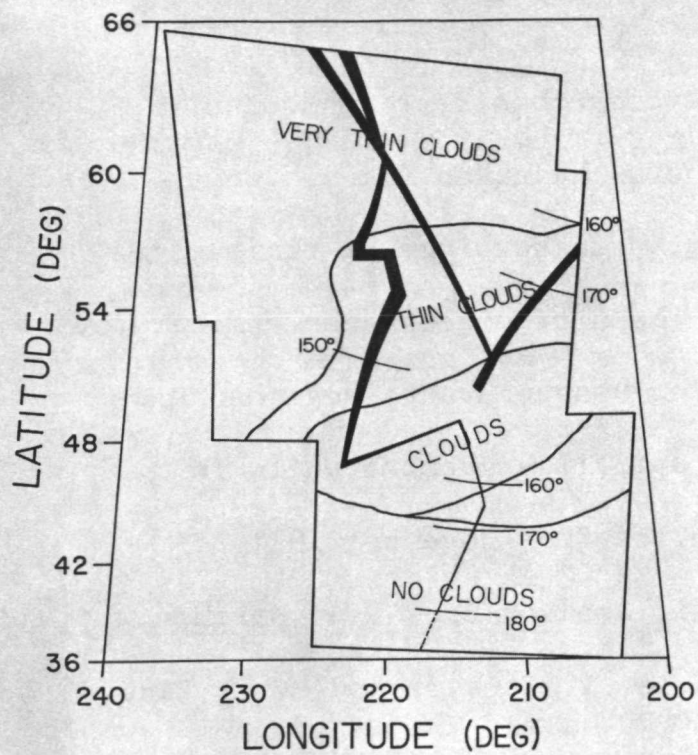
Data obtained on both the Orbiting Geophysical Observatories OGO-5 and OGO-6 are being used by Dr. G. E. Thomas to develop hydrogen models for the Earth's atmosphere and applying to them a new radiative transfer calculation

technique to predict geocoronal hydrogen Lyman alpha between 400 and 1100 km. The presence of a "geotail" was discovered by Drs. Bohlin and Thomas from the OGO-5 data and work has continued in the interpretation of this phenomenon.

Mars

Much of the recent LASP research effort conducted in the area of planetary atmospheres has been focused on the analysis and interpretation of data obtained by the Mariner 9 Mars Orbiting spacecraft. The ultraviolet spectrometer (UVS) experiment on board the Mariner 9 spacecraft, designed and built by LASP, obtained half a million spectra while in Mars orbit during the time period from November 1971 to October 1972. The mission, directed by Dr. C. A. Barth, together with Drs. C. W. Hord, A. I. Stewart and A. L. Lane was an unqualified success. Drs. K. D. Pang and D. J. Strickland also worked on this project.

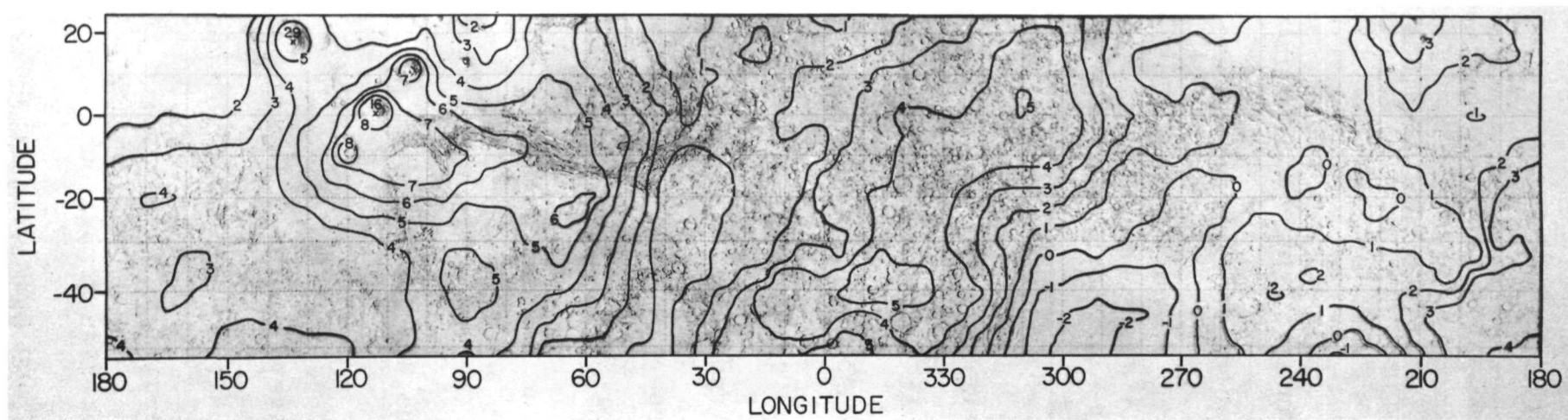
Analysis and interpretation of the Mariner 9 ultraviolet data have revealed a number of interesting facts. Measurements during the great Mars dust storm of 1971 showed that the dust particles were about 5 microns or smaller and the



dust was observed to settle with a 60 day time constant. Observations showed that individual dust particles scattered with 20% efficiency, absorbing the remainder of the solar radiation. The thickness of obscuring dust was found to be greatest in the Mars equatorial region with less dust occurring in the southern polar region.

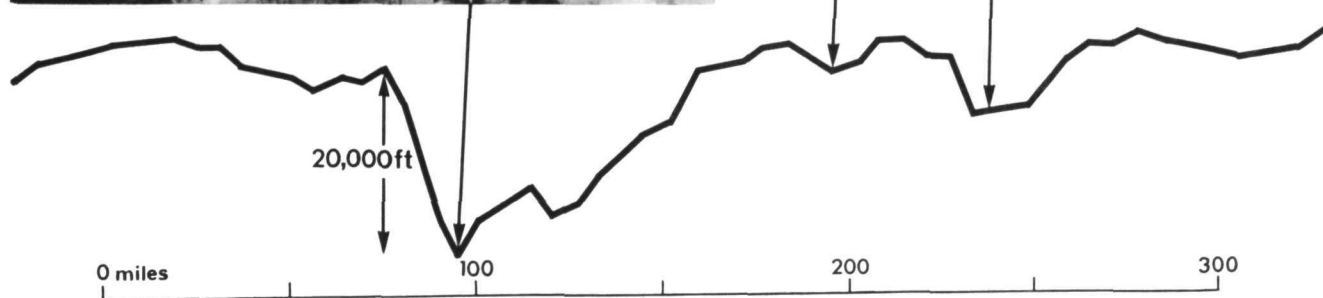
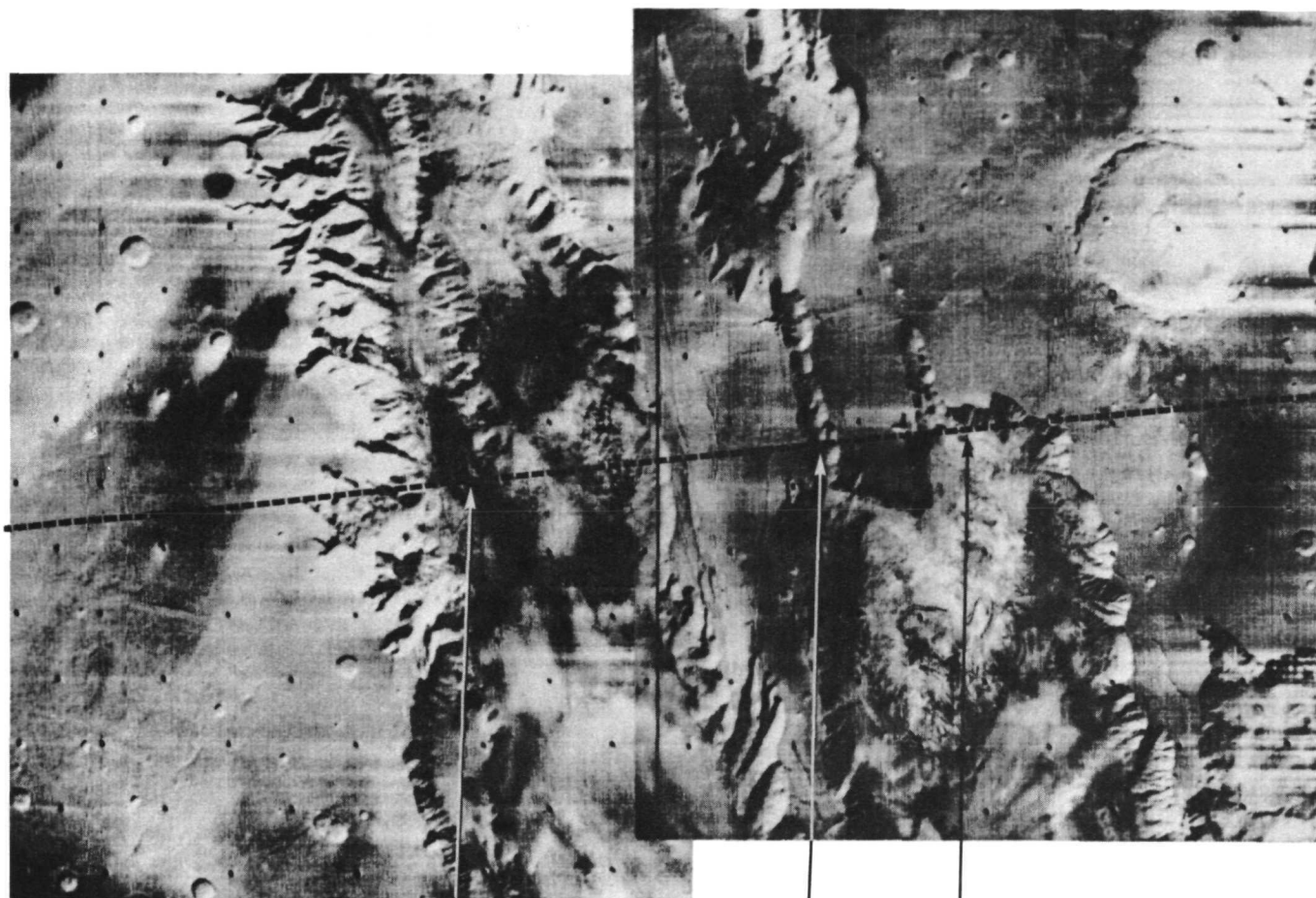
Ozone is observed in the polar regions of Mars and is found to vary by more than a factor of 10. In the summer hemisphere no ozone is seen in the polar region; however, the opposite pole, the winter pole, is observed to have ozone. The maximum amount of ozone observed is about one-hundredth that of the Earth's atmosphere. Ozone has not been observed in the Martian latitudes from 45°S to 45°N . The amount of ozone may be controlled by water vapor in the atmosphere. The largest amounts of ozone are observed where the atmosphere is cold and, therefore, dry. This is illustrated on the lefthand-side of the figure where the amount of ozone along the observational track is depicted by the thickness of the dark line. The location of clouds, obtained from the TV pictures on the righthand-side of the figure, is also shown. The amount of ozone increases and the clouds appear where the temperature, indicated along the track, drops below 180°K .

A thin haze or cloud layer was found to exist in the equatorial latitudes. Ultraviolet spectrometer measurements made at the Mars terminator and bright limb show this



thin layer to be at an altitude of 60 to 90 kilometers, and to be thicker in the morning than in the evening. This is apparently the result of condensate formation at night.

One of the objectives of the Mariner 9 ultraviolet spectrometer experiment was to map the surface pressure over a major portion of Mars. This work was carried out by Dr. Hord. Altitude contours determined from these pressure measurements are shown in the figure. The method is based upon Rayleigh scattering (sky light) from the molecules in the Martian atmosphere. Low areas such as Hellas, a large circular Mars desert, appear bright in the ultraviolet because of the larger number of gas molecules above the surface. In the higher Tharsis region, a smaller number of gas molecules exist above the surface and the corresponding ultraviolet intensity is less bright. Using the highly detailed ultraviolet altitude measurements, obtained every 30 kilometers, along a continuous track of measurements made each day during the mission, altitudes of the Martian volcanos have been obtained. The highest of these, Nix Olympica, rises to an altitude of 80,000 feet above its base.



Similar measurements across the great Martian rift (Mars Canyonlands) show that the rift has a depth of 20,00 feet as shown in the figure.

Between November 14, 1971, (orbit insertion) and March 22, 1972, 56 altitude profiles of Mars' airglow spectrum were recorded. The airglow is caused by ultraviolet and ionizing radiations from the sun falling at the upper atmosphere. Profiles of the strongest airglow emission, the Cameron bands of carbon monoxide, have already been analyzed for temperature and intensity information. Variations in intensity have been explained in terms of the Sun-Mars-instrument geometry and variations in solar activity during the observing period. However, the changes in temperature were greater than would be explained by purely solar effects. A more detailed study of the Cameron bands and other strong airglow emissions from atomic oxygen and ionized carbon dioxide is now underway. The results of this study will throw more light on the reasons for the variable temperatures. They will also provide a better picture of the composition and structure of the Martian upper atmosphere and ionosphere.

The composition and vertical structure of the Martian ionosphere is affected by, among other things, the intensity of solar ionizing radiation, the conversion of carbon dioxide ions to molecular oxygen ions by atomic oxygen, and the

diffusive separation of these ions at high altitudes. A computer program will be used to aid in the interpretation of the airglow data mentioned above, and in exploring the relationships between the airglow measurements and the measurements of the Martian ionospheric electron density made by the Mariner 9 S-band occultation experiment.

Another theoretical study of the Martian upper atmosphere is addressed to the energy distribution of the photoelectrons produced by the solar ionizing radiations. In previous studies of this distribution, it has been assumed, for ease of computation, that an initially fast-moving photoelectron will lose its excess energy in a continuous manner; the present work takes account of the loss of energy in discrete amounts due to inelastic collisions between the electron and the molecules of carbon dioxide which make up the bulk of the Martian atmosphere. An example of such a collision is the dissociation, by the photoelectron of the CO_2 molecule, into atomic oxygen and electronically excited carbon monoxide, which then radiates a photon in the Cameron band system and so contributes to the ultraviolet airglow observed by the UVS Mariner 9 instrument. The results of this work will be applied to the interpretation of Martian

airglow data. These studies of the upper atmosphere of Mars are being carried out by Dr. Stewart.

The third study under way is concerned with the photochemistry of water vapor and ozone in the lower atmosphere of Mars. Dr. Barth's analysis of ozone measurements indicates that water vapor plays a very important catalytic role in the recombination of carbon dioxide following dissociation by ultraviolet sunlight, but the mechanism is as yet incompletely understood. One theory of the process requires very vigorous vertical mixing of the atmosphere to carry atomic oxygen produced when carbon dioxide is dissociated, downwards from high altitudes (where it tends to form molecular oxygen) to regions near the surface of the planet (where it readily reacts with carbon monoxide to form carbon dioxide again). However, measurements of the temperature structure of the atmosphere by Mariner 9 experiments do not support the presence of such vigorous mixing. A second theory suggests that the molecular oxygen formed in the absence of vigorous mixing may be destroyed by a chain of reactions involving hydrogen peroxide. The testing of these theories is aided by the measurements of ozone on Mars by the UVS Mariner 9

instrument, since ozone is intimately related photochemically to atomic and molecular oxygen, and is thus sensitive to the details of the mechanisms controlling the abundance of these gases and their recombination with carbon monoxide to form carbon dioxide. A computer program has been written by Dr. Stewart to explore the possible photochemical models of the Martian atmosphere, consistent with the measurements of ozone, water vapor, temperature, and other quantities by the Mariner 9 experiments.

A theoretical model for the production of the 4th Positive bands of carbon monoxide in the Martian atmosphere is being developed by Dr. G. E. Thomas. The positive detection of carbon monoxide in the thermosphere of Mars has lead to the proposal of a new mechanism for production of this particular emission.

Venus

A LASP instrument has been provisionally accepted as part of the scientific payload for the Pioneer Venus entry probe mission in 1978. The instrument will be the latest in the line of LASP ultraviolet spectrometers, being 6 times as light and occupying 8 times less

space than the Mariner 6, 7 and 9 instruments. It will be carried on the "bus" part of the spacecraft, which, after releasing four landing probes, will enter the Venus atmosphere and make measurements at ionospheric altitudes before burning up. The spectrometer will study the day and night airglow emissions on Venus, providing information on the composition, temperature and physics of the Venus upper atmosphere. It will also study the scattering properties of the venus cloud tops. The experiment will be directed by Drs. Stewart, Barth and Hord.

The Moon

Drs. C. A. Barth, C. F. Lillie, W. H. Moos, and G. E. Thomas collaborated in a Johns Hopkins University ultraviolet spectrometer experiment on board the Apollo 17 lunar-orbiting command module. Preliminary results show that there is much less hydrogen in the lunar atmosphere than expected. Xenon and carbon were also searched for--but none found. Atomic hydrogen was expected to be a major component of the Moon's atmosphere, but it is not. There is apparently very little,

if any, outgassing--a process by which elements that originate in the interior of a planet are released, thus helping to create an atmosphere. The absence of atomic hydrogen, expected to be present from the solar wind source, leads to the conclusion that solar wind protons are neutralized and converted to hydrogen molecules at the lunar surface. While in lunar orbit, the Moon's horizon was used as an occulting edge to make measurements of the interplanetary medium in the direction of the Sun.

Measurements were also made of the solar ultraviolet radiation reflected from the surface of the Moon. During part of the return flight to Earth, additional measurements were made of stellar objects, as well as emissions from galactic sources.

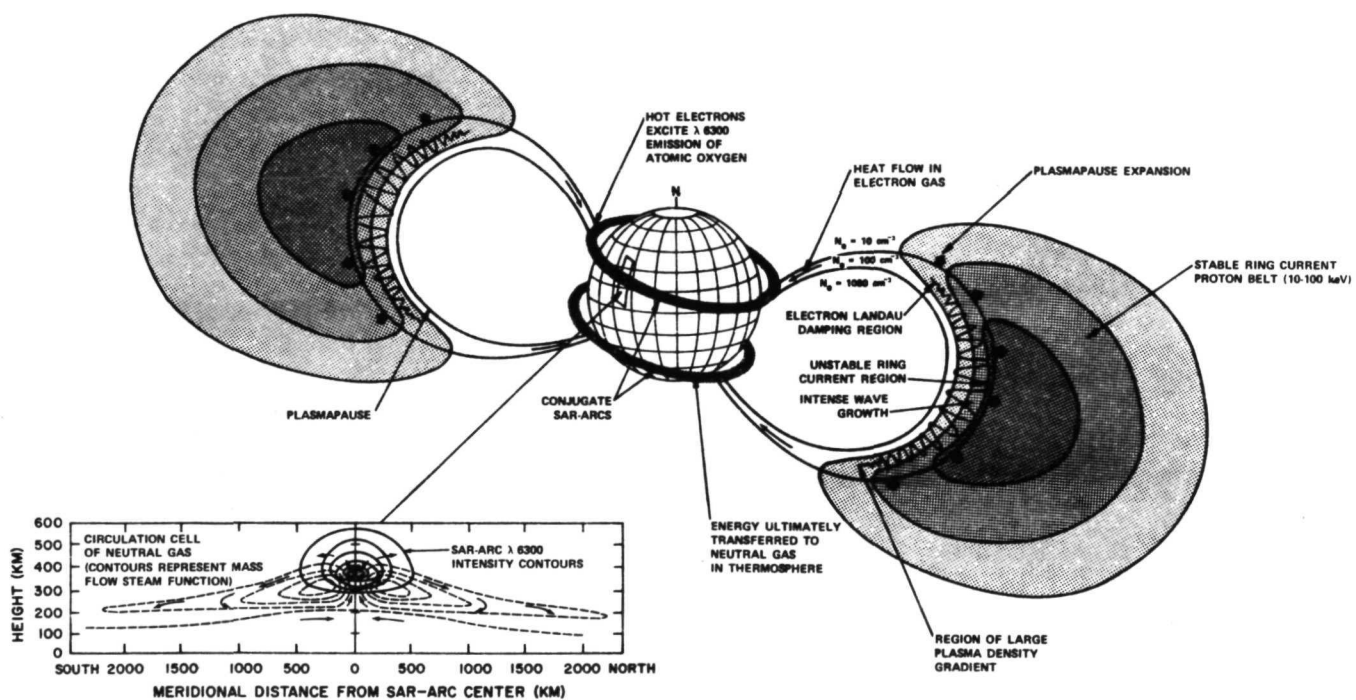
Auroral Phenomena

Unique phenomena occur on planets that possess a substantial magnetic field. In the solar system, the two planets of interest are the Earth and Jupiter. These phenomena are a consequence of the interaction between the solar wind and the magnetic field surrounding the planets. The charged particles that constitute the solar wind are trapped by the magnetic field and, after some time has

elapsed during which their energy and direction of motion may be altered, they may be dumped into the atmosphere. The aurora is the most spectacular consequence of the interaction between energetic particles and the planet's atmosphere. Detailed study of the spectroscopic emission features in aurora provide information about the planet's atmosphere and ionosphere as well as the characteristics of the bombarding particle flux. LASP is engaged in a continuing program of auroral studies. With the abundance of available observational data much effort has been devoted by Dr. M. H. Rees to developing models that provide a physical description of the phenomena. The models must correctly predict the ion density and composition in the ionosphere, the electron and ion temperatures, the spectroscopic emissions, and perturbations of the neutral atmosphere. The physical processes are coupled, leading to complex mathematical descriptions of the problems. Models have been developed for aurora on Earth. The magnetic field of Jupiter is considerably larger than that of the Earth; the solar wind strength at Jupiter's orbit is weaker; Jupiter's atmosphere is predominantly molecular hydrogen. Therefore, "aurora" on Jupiter should be rather different compared to Earth; nevertheless the formulation of the models and the

mathematical techniques are comparable. Many assumptions and much speculation are involved in the initial modeling of aurora on Jupiter. The Pioneer satellites and the planned Mariner Jupiter/Saturn mission in 1977 should provide valuable relevant observations.

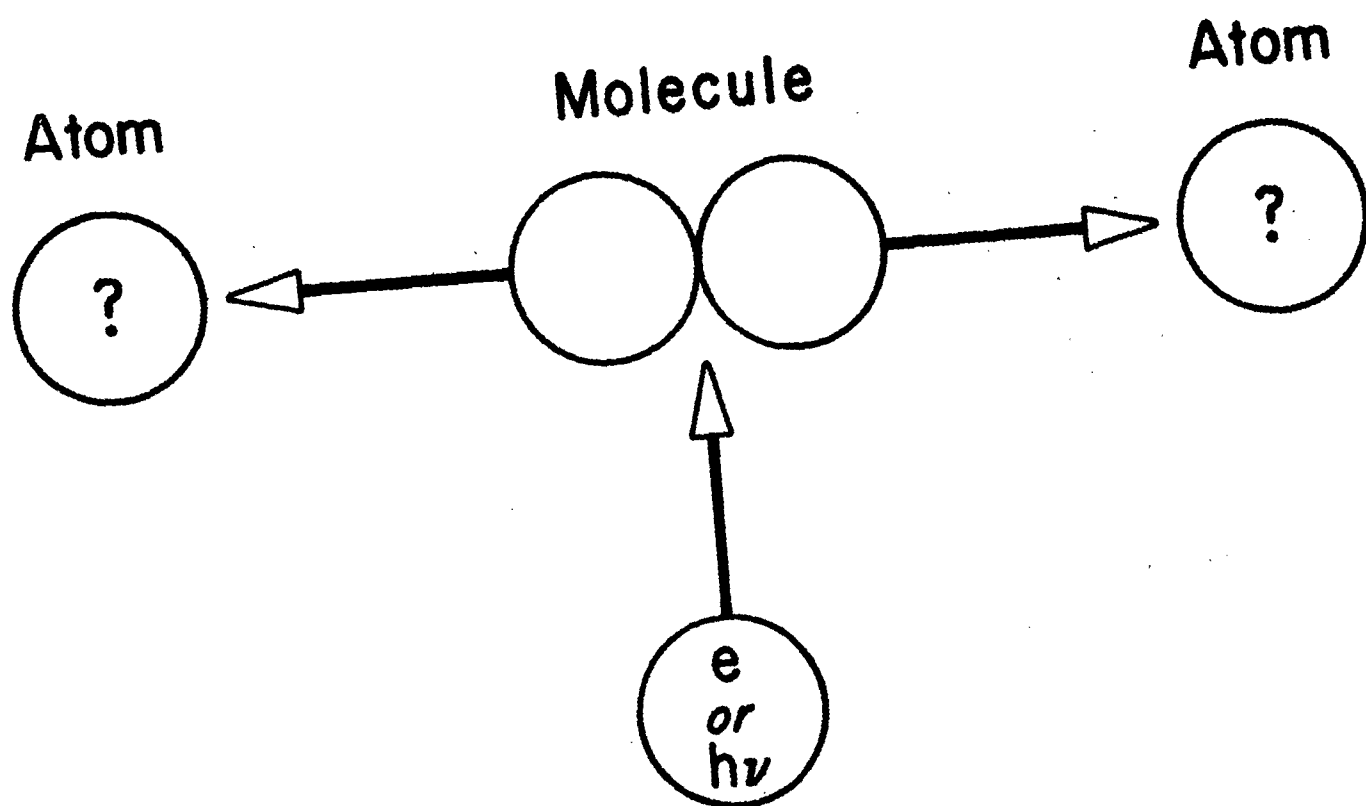
A phenomenon associated with large magnetic and auroral storms and studied by Dr. Rees is the enhancement of the red triplet emission of atomic oxygen; the brightest component of the triplet has a wavelength of 6300 \AA . The emission is in the form of a pair of conjugate circumglobal arcs that are observed at geomagnetic latitudes corresponding to Boulder. This phenomenon is named SAR arcs (Stable Auroral Red Arcs). A definitive study of SAR arcs has been completed, reviewing the observational characteristics and providing a detailed theoretical analysis. The production of SAR arcs is illustrated schematically in the figure. There is a region in the magnetosphere where energetic protons form a ring current in the shape of a torus enveloping the Earth. The plasmopause is the outer boundary of the dipole-like closed magnetic field configuration of the magnetosphere that contains a region of high density plasma. Outside this boundary the magnetic field lines sweep into an extended



tail on the antisolar side, and the plasma density drops sharply. During large auroral storms, the plasmapause moves radially outward toward the region of the proton ring current. The large plasma density gradient of the plasmapause causes instabilities to form in the proton ring current and also causes the growth of waves, at the expense of the proton energy. The waves are, in turn, damped by the ambient plasmapause electrons producing a substantial increase in electron energy. The hot electrons move into the atmosphere where, by coulomb interactions the temperature of the electron gas is enhanced. The population of electrons in the high energy tail of the maxwellian distribution is sufficiently large to cause excitation of oxygen atoms into the 1D state, from which the 6300 Å radiation originates. There is some heating associated with the formation of SAR arcs causing the formation of weak large scale circulation cells in the neutral atmosphere. SAR arcs illustrate the wide range of fields in physics required to understand geophysical phenomena.

Laboratory Studies

The laboratory program in physical chemistry and in spectroscopy, directed by Dr. G. M. Lawrence, has three



general goals. They are: the quantitative study of atomic and molecular processes which are needed in the analysis of atmospheric data; communication with the other laboratories concerning needed data; development of new techniques for use in flight instruments and their calibration.

Molecular dissociation is being extensively studied in the laboratory. The emphasis is on determining the internal energies of the fragments produced by impact of electrons and photons on various atmospheric molecules. The question marks on the figure indicate the interest in the states of the fragments. Although much work has been done in the past on dissociation processes in general, few experiments tell anything about the internal energy levels produced. Since many atmospheric processes are not in equilibrium, these internal energies play a crucial role. Hence this lack of knowledge is a major limiting factor in the understanding of atmospheric gas reactions.

The difficult experimental problem in these studies has been the lack of a sensitive detector for neutral, weakly excited atoms. For example, a study of the reaction of active nitrogen with sodium sulfate showed a greenish glow with a broad continuous spectrum. This glow however, was shown to be too inefficient to make a useful detector

of atomic nitrogen. The development of sophisticated UV resonance techniques and of a high efficiency ionizer has fostered progress toward this goal.

A time-of-flight experiment to measure the energies of photofragments of molecules is underway. The data will be used directly in the analysis of atmospheric process and will provide a much needed check of dissociation theory.

During the past year, many processes that play important roles in the atmospheres of the planets have been studied. A quantum theoretical study of the transition probabilities of the carbon monoxide 4th Positive band system is almost complete and will yield ideal standards in molecular branching ratio calibrations.

Another experiment to measure the absorption strength in molecular ions, such as CO_2^+ , N_2^+ and NO^+ , is being developed and can be applied to the problem of tracing pollutants in the atmosphere, as well as for basic studies of the molecules.

Because of the wealth of atmospheric data collected by the Mariner orbiting ultraviolet spectrometer, laboratory studies on the production of the species observed in the

Martian atmosphere were made. The laboratory measurements on atomic oxygen production and CO Cameron band formation have been used in the interpretation of the atmosphere of Mars and the Earth. These studies were conducted by Dr. G. M. Lawrence in collaboration with Drs. H. M. Poland, S. C. Seitel and a LASP visiting fellow, Dr. M. J. McEwan.

In the development of new techniques, a new detector has been developed that is 200 times as sensitive as instruments currently in use, such as the scanning monochromator. The method uses a Bendix Chevron plate and a resistance strip anode. It is hoped that a further increase of sensitivity, up to one thousand, can be obtained. This technique promises to be very important for future space exploration, in the search for low abundance constituents of a planetary atmosphere.

A sounding rocket to be launched in the fall of 1973, will artificially create, above 200 km, an "atmosphere" of CO_2 , CO, NO and H_2 . Instruments on board the rocket, will study some of the basic parameters used in atmospheric modelling: the solar flux ; the excitation cross sections of the molecules and atoms; and the instrument sensitivity of a Mariner-type spectrometer, will be determined.

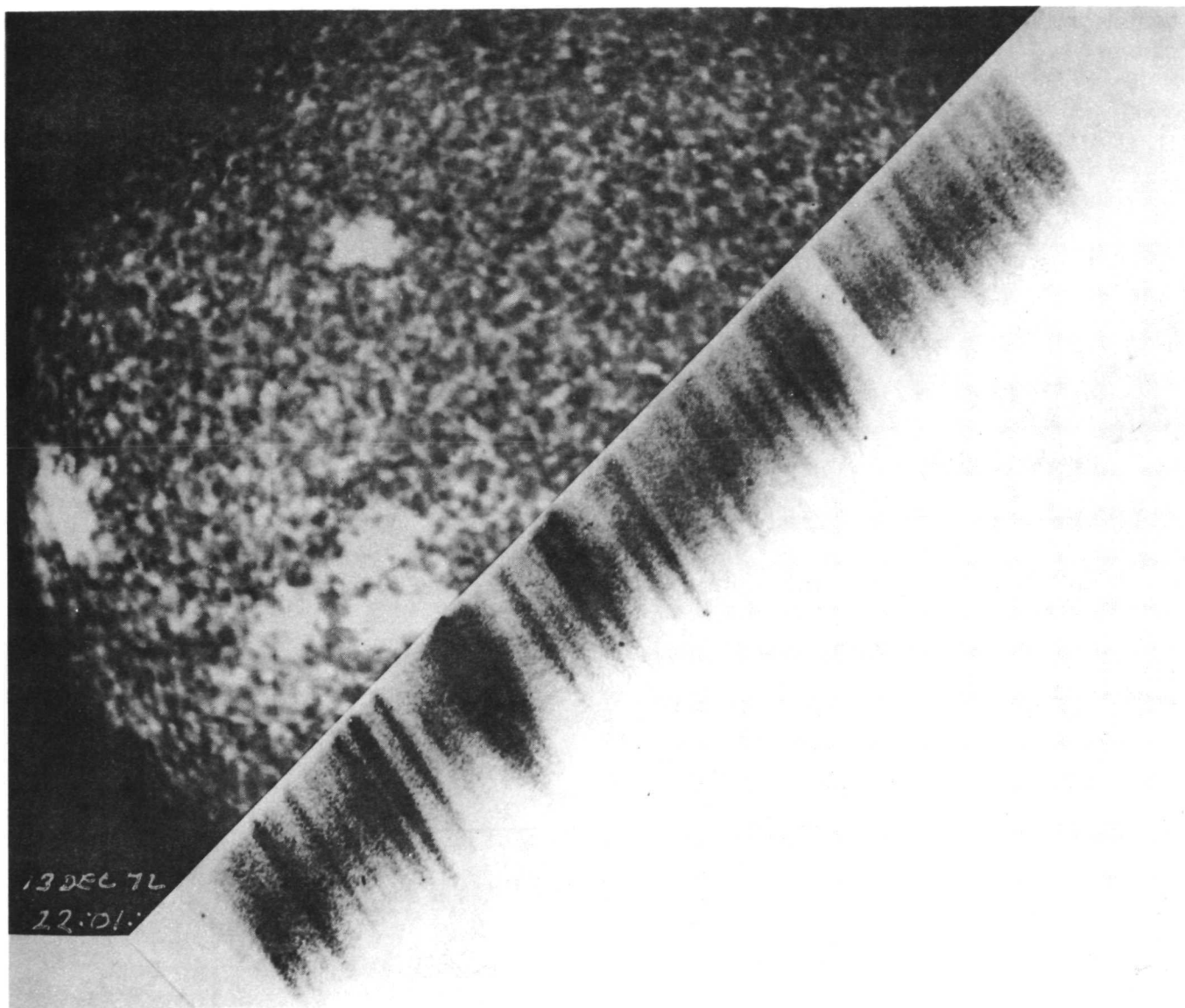
Solar Physics

The OSO-I program, now entering the third year, is a major LASP effort directed toward a study of the solar chromosphere, transition region, and lower corona. The program, being carried out under the direction of Dr. E. C. Bruner, Jr., in association with Drs. E. G. Chipman, B. A. Domenico, G. J. Rottman and visiting scientist, Dr. H. C. McAllister. The instrument being developed for this program is a high resolution spectrometer covering the wavelength region between 1050 Å and 2300 Å. The instrument has been designed to produce a spectral resolution of .01 Å (one part in 10^5) between 1050 Å and 1800 Å, and will resolve .02 Å at longer wavelengths. Angular resolution on the solar disk is variable, ranging from the full slit defining a field of 1 arc sec by 15 arc mins to a minimum field of 1 by 3 arc seconds. Other intermediate fields are selectable by means of a slit masking mechanism.

The spectrometer is computer controlled and is nearly as versatile as a ground based observatory in its ability to carry out complex observing programs. One of the most important uses of the new facility will be a study of systematic velocities in the solar atmosphere as revealed

by doppler shifts in the spectral lines. Mechanical motions, such as shock waves, are thought to be the mechanism responsible for heating of the solar corona. Theories of line formation in the presence of sound or shock waves predict systematic changes in the line profile that can be directly verified by the instrument.

A preview of the quality and type of data to be received from OSO-I was given by the successful launch of a sounding rocket on December 13, 1972. This rocket carried as its principal experiment an improved echelle spectrograph which photographed the spectrum between 1190 Å and 1320 Å with the highest spectral resolution achieved to date (.01 Å) and with sufficient angular resolution to reveal the so-called supergranulation or chromospheric network. This experiment demonstrated what some solar astronomers have long suspected, that emission lines, arising in the chromosphere and transition zones, are greatly enhanced on the boundaries of the supergranulation network as defined by the calcium K line as shown in the accompanying photo. The experiment further demonstrated that the physical conditions leading to the formation of the hydrogen Lyman alpha line can vary considerably from place to place on the sun. The difference is particularly noticeable when comparing interiors



of the supergranulation cells to their boundaries. The detailed interpretation of these data have just begun, but they have already generated a great deal of excitement in the solar physics community.

A number of collaborative programs have developed during the course of the OSO-I program. The participation of Dr. R. G. Athay of HAO-NCAR as Co-Investigator and the organization of the International Users Group, to operate the observatory in orbit, have been discussed in previous reports of our activities. Very close collaboration continues between LASP and the Laboratory for Stellar and Planetary Physics (LPSP) of Paris, France, who are conducting the other major experiment on OSO-I. During mission operations, the French scientific team will reside in Boulder, and will operate their experiment from the LASP control center. Equipment, software and perhaps even personnel in some cases will be shared to maximize the scientific returns from the two experiments.

A second collaborative effort involving LPSP is the joint calibration rocket program which will support OSO-I after launch. Current plans call for two rockets to be launched during each year of operation: one will be supplied

by NASA and launched from the White Sands Missile Range while the second will be supplied by CNES, the French Space Agency, and will be launched from the Kourou Space Center in French Guiana. Data from the calibration flights will be made available to both experiment teams and to the International User's Groups.

A third collaborative program which has developed recently will combine a LASP experiment by Dr. W. A. Rense and a LPSP experiment by Dr. J. F. Crifo into a single rocket payload. The two instruments will make intensity and line profile measurements of the solar He 584 Å resonance line, using different, but complementary techniques. These experiments are to be timed so that the measurements will support an experiment on board Pioneer 10, when that spacecraft encounters Jupiter in December 1973. The latter experiment, conducted by Dr. Darrell Judge of the University of Southern California at Los Angeles, will measure the intensity of a possible He 584 Å airglow from Jupiter. Dr. Judge requires a knowledge of the solar 584 Å line profile and intensity in order to be able to analyze his data.

Another joint project is being conducted by LASP,

the Sacramento Peak Observatory, the Los Alamos Scientific Laboratory and the Sandia Corporation. In this experiment which must be conducted during a total eclipse, the profile of the hydrogen Lyman alpha line in the solar corona will be measured. This line is formed by resonance scattering of light from below by the few remaining neutral hydrogen atoms remaining in the corona (most are ionized by the million degree temperatures of the corona). From the width of the profile, the kinetic temperature of the atoms in the corona can be inferred and the variation of temperature with height determined. These measurements are currently of great interest and are expected to add considerably to the understanding of the physics of the corona.

Space Astronomy

The space astronomy program at LASP encompasses a wide range of research, from studies of the extragalactic medium to the atmospheres of peculiar stars to a program for in situ observations of the outer planets and the rings of Saturn. These investigations, under the direction of Dr. C. F. Lillie, are being conducted with measurements from a variety of experiments aboard rockets, satellites and interplanetary probes, supplemented with observations

from ground based telescopes. The complementary solar and planetary programs of the laboratory use the same observational and theoretical techniques to study the sun, the outer planets, the stars in our galaxy, and beyond. The program is divided into three basic activities: the analysis of data from previous missions; the preparation of new experiments for launch; and planning for future investigations.

The laboratory is currently engaged in the analysis of stellar data from experiments aboard the Orbiting Astronomical Observatory (OAO-2), the Mariner 9 Mars Orbiter, the Apollo 17 mission and a rocket. The analysis of OAO observations of the interstellar medium has revealed the presence of large numbers of very small dust particles, which play an important role in determining the physical condition of material between the stars, the material from which new stars and planets form.

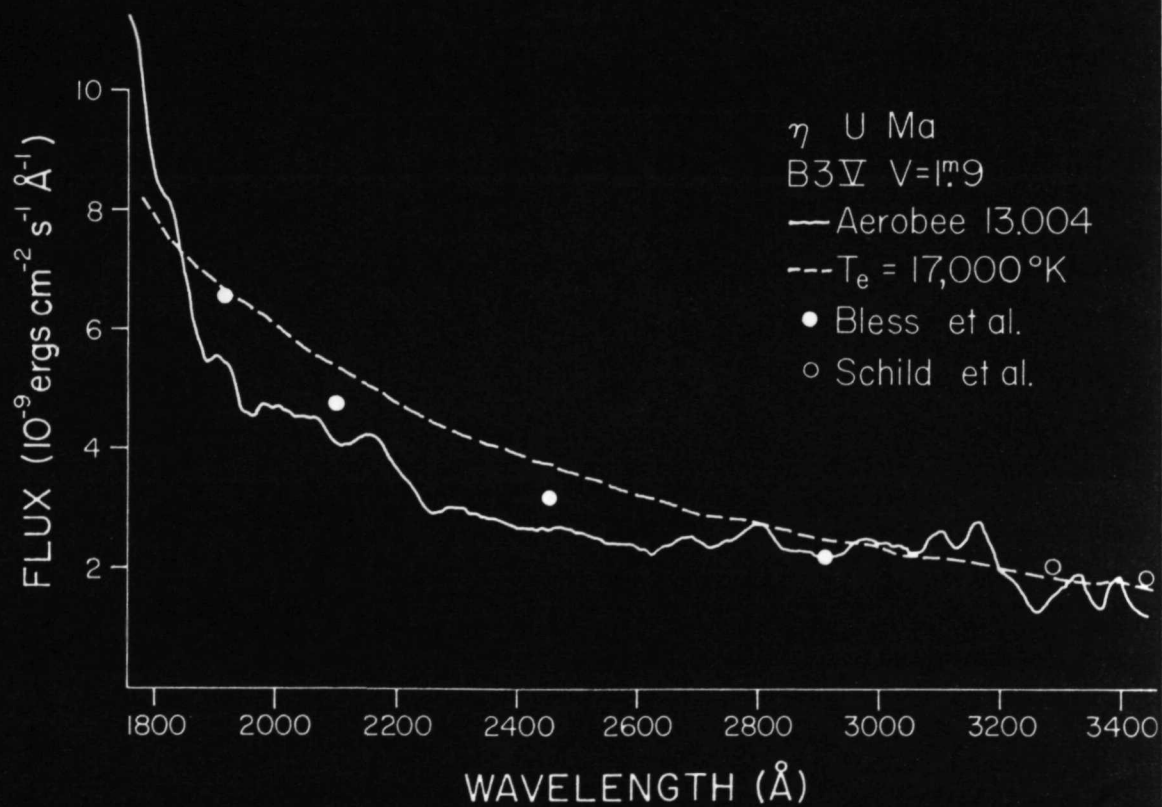
During a part of its orbit, Mariner 9 was unable to view Mars and was used instead for stellar observations. A new temperature scale for hot stars has now been established and the number of hydrogen atoms between the Earth and these stars measured. The data have also been used to set limits on the amount and temperature of hydrogen gas in clusters of galaxies. This gas is thought to contribute to the

binding of galaxies together gravitationally, as well as providing material for the formation of new galaxies. This analysis was carried out by Drs. R. C. Bohlin and M. R. Molnar.

The Apollo 17 experiment was basically designed to detect the presence of the lunar atmosphere, but additionally was used to observe gas and dust in the interplanetary medium. Analysis is underway to determine the size and composition of this dust between the planets.

One of the current problems in space astronomy is a determination of the exact brightness of stars in the 1000 - 3500 Å spectral region, for comparison with stellar atmospheric structure models. A recent rocket flight took the measurements shown in the figure. The observed measurements are compared with a theoretical model, ground based observations and other rocket observations.

A sounding rocket to be launched in January 1973, will carry a payload consisting of polarimeters to measure the surface brightness of the night sky. Eight wavelengths in the 1400 - 8200 Å region will be used to study the scattering properties of interplanetary dust grains.



A LASP experiment will be flown past Jupiter and Saturn on a Mariner spacecraft in the late 1970's. These planets, their satellites, and the rings of Saturn and the space environment near the planets will be studied to learn more about their composition and structure to determine whether conditions suitable for life exist in the outer planets.

Future satellite experiments include the International Ultraviolet Explorer (IUE). Large Space Telescope (LST), and the Space Shuttle. Dr. M. R. Molnar will be a guest observer during the coming year on the OAO-3 Copernicus satellite to study ϵ UMa, an Ap type star. Comet Bennett (1969) was observed for over a month by the LASP photometer experiment on board OGO-5. Reduction of the data has shown that the comet is enveloped in a very large hydrogen cloud. Drs. G. E. Thomas and H. U. Keller have made models for the Production and maintenance of such a large cloud of gas. LASP scientists plan to observe a bright new comet, Kohoutek (1973f) late in 1973 with rocket and ground based instruments and have proposed using the new OAO-3 Copernicus for satellite observations.

Visiting IASP Fellows 1972 - 1973

Dr. Murray McEwan of the University of Canterbury, Christchurch, New Zealand, has measured the $O(^1S)$ quantum yields from the vacuum UV photolysis of O_2 and N_2O . Other gases also studied were NO_2 and O_3 . The results at present are being interpreted and will have some bearing on the $O(^1S)$ intensities around 100 km in the terrestrial atmosphere.

Work will start shortly on an absorption experiment intended to be capable of detecting absorptions as small as 1 part in 10^6 . The experiment was originally designed to measure the absorptions of ions such as CO_2^+ but may be extended to look at the absorption of ozone produced by photolysis of CO_2 "snow".

Dr. Stanton Peale, of the University of California, Santa Barbara, is working on developing a theory of rotating solar system bodies. Additional special effects, such as non-principal axis rotation and elasticity, are included to treat rotational and tidal distributions of bodies. The theory has been applied to the Moon and to Mercury in particular.

Dr. H. Warren Moos, of Johns Hopkins University, Baltimore, Maryland, has been working on the analysis of UV rocket spectra acquired from a successful flight in August, 1972. Data of the Jovian UV spectra are under study now, together with data of the chromospheric emissions of the K giant, α Boo, obtained from the same rocket flight. This analysis is being conducted with the use of the LASP interactive data analysis system (PDP-8).

Dr. Moos is a co-investigator on the Apollo 17 UV spectrometer experiment, flown in December, 1972. A large quantity of data was acquired, and is now under analysis.

LASP Space Participation

1965 - OGO-2 } Two channel ultraviolet scanning spectrometer
1967-9 - OGO-4 } to measure the Earth's airglow and auroral
emissions in the wavelength region 1050 - 3350 Å.

1967 - Mariner 5 Three channel photometer to measure the hydrogen and oxygen emissions in the atmosphere of Venus. During the interplanetary flight, observations were made of O, B and A stars as well as the interplanetary background emission.

1969 - Mariner 6 & 7 Ultraviolet observations of Mars using a scanning spectrometer to determine the constituents of the atmosphere.

1969-72 - OSO-V Three channel broad band EUV spectrometer photometers to monitor solar emission in the wavelength intervals 280 - 370 Å, 465 - 630 Å and 760 - 1030 Å.

1971-2 Mariner 9 Orbiting spacecraft carrying an ultraviolet spectrometer to measure the constituents of the Martian atmosphere, the variation of the atmosphere over five months of observations and measurement of the UV spectrum of stellar objects.

1972 - Apollo 17 Co-investigators with Johns Hopkins University to measure the ultraviolet spectrum of the lunar atmosphere, and the amount of minor constituents of that atmosphere. In addition, a sequence of observations were made to determine the sky background in the ultraviolet. Many stellar objects were also observed during the trans-lunar flight.

LASP Future Space Participation

Probable Launch Date

Spacecraft

Principal/Co-Investigator

Scientific Objectives

November 1973

Atmospheric Explorer-AE-C

C. A. Barth

A. I. Stewart

An ultraviolet spectrometer will be used to measure nitric oxide in the upper atmosphere of the earth. Changes in the distribution of nitric oxide as a function of solar activity and atmospheric changes will be correlated with measurements made by other atmospheric and solar instruments on board the satellite.

November 1974

Orbiting Solar Observatory

OSO-I

E. C. Bruner

High resolution spectrometer to measure solar line profiles in the 1090 - 2300 Å region. The experiment will study the physical conditions in the solar chromosphere, transition zone, and lower chromosphere. It will be able to directly measure the velocities of large gas clouds in the solar atmosphere and to infer the velocity spectrum of turbulent motions of smaller scale. A search will be made for evidence of shock waves, thought to be responsible for the existence of million degree temperatures found in the corona.

April 1975

Atmospheric Explorer-AE-D

C. A. Barth

A. I. Stewart

The ultraviolet nitric oxide instrument will be used to measure changes in the amount of nitric oxide in the atmosphere that occurs as the result of auroral activity. These measurements will be correlated with other properties of the atmosphere that will be measured by the other instruments on board.

1977

Mariner Jupiter/Saturn

C. F. Lillie

C. W. Hord

K. D. Pang

A photopolarimeter will study the surfaces and atmospheres of the two planets; of especial interest are the studies of the rings of Saturn. In addition it will measure properties of interplanetary dust particles and the diffuse galactic light.

1977

Mariner Jupiter/Saturn

J. W. Warwick

A radio detection system will be used to study the sources of the planetary radio emissions, search for magnetic fields on the outer planets, and seek to define and explain relationships between the planets and their satellites, search for the presence of lightning. Solar radio emission will be studied from new directions in space.

LASP Future Space Participation (Continued)Probable Launch DateSpacecraftPrincipal/Co-InvestigatorScientific Objectives

1977

International Ultraviolet
Explorer

A. L. Lane/C. A. Barth

Observation of Mars over a 3 - 5 year period from a multinational spacecraft. The continuous monitoring of Mars will be able to detect local changes in ozone concentration and variations in dust in the atmosphere. Seasonal changes will be monitored for more than one Martian year (1.9 Earth years). The experiment can also be used to observe other planets.

1977

International Ultraviolet
ExplorerP. Conti/J. Castor/
D. Hummer/C. Lillie/
D. Mihalas

This joint experiment, by several co-operating research institutes in Boulder, will make spectroscopic observations of O, Of and Wolf-Rayet stars to study the atmospheric structure of typical stars in these classes.

1978

Pioneer Venus

A. I. Stewart/C. A. Barth/
C. W. Hord

Analysis of the Venus upper atmosphere and cloud tops by an ultraviolet spectrometer to be carried into the atmosphere by the Pioneer Venus spacecraft. The analysis will be directed primarily at the questions of composition, energy balance, and escape of atomic hydrogen.

1979

Shuttle - Earth
Resources

C. A. Barth

At present the LASP is participating in design studies to measure global ozone and nitric oxide distributions in the Earth's atmosphere.

1980

Shuttle - Large Space
Telescope

C. F. Lillie

The laboratory is participating in studies of this new telescope, designed to be used for at least 10 years. The telescope will be used for planetary, stellar and galactic studies, with at least 20 times better resolution than obtainable from the Earth's surface.

Recent Rocket Launches

Rocket # Launch Date	Scientist	Objective
5/31/72 21.001	Rense/ Bruner	Echelle and grazing incidence spectrographs to measure the solar ultraviolet line profiles in high resolution. SPARCS failed. Echelle reflown on 13.094. Grazing incidence spectrograph to be reflown on 21.007.
7/13/72 13.004	Lillie	Mariner 6 and 7 instrument used to obtain stellar ultraviolet spectra for comparison with Mariner 9 data.
11/3/72 14.487	Barth/ Greer	Reflight of 14.464. Successful detection of ultraviolet night airglow.
12/13/72 13.094	Bruner	Echelle and 1/8m spectrograph measured solar line profiles in high resolution and absolute solar fluxes. Flown in conjunction with the Apollo 17 moon flight.
5/18/73 21.019	Barth/ Kelly	Nitric oxide scattering cell with filters measured the fluorescence of NO in the Earth's atmosphere. A flowing oxygen cell ion chamber measured the solar Lyman alpha line intensity at the same time.

Future Rocket Launches

<u>Rocket No. & Type</u> <u>Date of Flight</u>	<u>Scientist</u>	<u>Objective</u>
18.153 Nike Tomahawk June 9, 1973	Barth/Good	Six photometer cluster to measure the daytime IR airglow
Black Brandt July 15, 1973	Barth/ von Zahn	Joint experiment with U. of Bonn, Germany to study the Earth's airglow, using photometers
21.007 Black Brandt VC August 1973	Rense	Solar grazing incidence high-resolution spectrograph, together with 1/8m spectrograph to measure the He 584 Å solar line
10.409 Nike Cajun September 1973 10.410 September 1973	Barth/Kelly	NO fluorescence measurement of the Earth's atmosphere with an on board light source
21.008 Black Brandt VC December 12, 1973	Rense/Bonnet	Solar grazing incidence spectrograph, together with a 584 Å He I absorption instrument, to be flown at the time of Pioneer 10 encounter with Jupiter
18.154 Nike Tomahawk December 1973	Barth/Broida/ Kelly	1/4m spectrometer to measure NO γ bands using a polarizer to discriminate against Rayleigh scattering. A NO resonance cell will be used to measure the solar flux

Future Rocket Launches (Continued)

<u>Rocket No. & Type</u> <u>Date of Flight</u>	<u>Scientist</u>	<u>Objective</u>
13.112 Aero- bee 170 January 1974	Barth/ Lawrence	A "simulated" Mars atmosphere experiment to determine physical parameters of important atmospheric processes
13.111 Aerobee 170 April 1974	Lillie	Zodiacal light experiment using 8 photometer/polarimeters, to be flown with the Dudley Observatory Skylab-type photometer, to study the interplanetary medium in the interval 1400 - 8200 Å
Terrier-Sandhawk June 20, 1974	Bruner	Eclipse shot to measure Lyman alpha profile in the solar corona as a function of height
18.155 Nike Tomahawk 1974	Barth/Kelly	1/4m spectrometer to measure the Earth's airglow
13.XX Aerobee 170 Fall 1975 13,XX Aerobee 170 1975 Veronique Fall 1975	Bruner	OSO calibration rockets. 1/8 meter 1 Å resolution instrument to measure the intensity of many lines in the wavelength interval 1000 - 3000 Å

FACULTYCharles A. Barth

Professor, Astro-Geophysics
Scientific Director, Laboratory for Atmospheric &
Space Physics
Ph.D. University of California, Los Angeles, 1958
University of Bonn, Germany, 1958-1959
Jet Propulsion Laboratory, California, 1958-1965
University of Colorado, 1965 - present

Herbert P. Broida

Research Associate (summers)
Ph.D. Harvard University 1949
National Bureau of Standards, 1949-1962
Imperial College, London, England, 1952-1953
University of Cambridge, England, 1959-1960
Professor, Physics, University of California,
Santa Barbara, 1962 - present

Elmo C. Bruner, Jr.

Research Associate, Lecturer
Ph.D. University of Colorado, 1964
Physicist, U. S. Naval Ordnance Test Station, China
Lake, California, 1957-1960
University of Colorado, 1964 - present

Charles W. Hord

Research Associate, Lecturer
Ph.D. University of Colorado, 1964
Southern Colorado State College, 1964-1966
University of Colorado, 1966 - present

George M. Lawrence

Research Associate, Lecturer
Ph.D. California Institute of Technology, 1963
Staff Physicist, Princeton University 1963-1966
Research Scientist, McDonnell Douglas, California 1966-1970

George M. Lawrence (cont'd)

Visiting Associate, California Institute of Tech. 1968-1970
Lecturer, California State, Long Beach, California, 1970
Visiting LASP-JILA Fellow, 1970

Charles F. Lillie

Assistant Professor, Physics & Astrophysics
Ph.D. University of Wisconsin, 1968
Research Associate, OAO II Program, University of Wisconsin
1968-1970
Instrumentation Engr. NASA Flight Research Ctr. 1960-1962
University of Colorado, 1970 - present

Manfred H. Rees

Research Associate, Lecturer
Ph.D. University of Colorado, 1958
Asst. Professor, University of Alaska 1958-1960
Senior Research Fellow, Queen's University
Belfast, Ireland, 1960-1961
Associate Professor, University of Alaska, 1965-1966
Research Associate, University of Colorado, 1961 - present

William A. Rense

Professor, Physics and Astrophysics
Educational Director, Laboratory for Atmospheric &
Space Physics
Ph.D. Ohio State University, 1939
Asst. Professor, Rutgers University, 1941-1942
Asst. and Assoc. Professor, Louisiana State
University, 1943-1949
University of Colorado, 1949 - present

A. Ian Stewart

Research Associate, Lecturer

Ph.D. The Queen's University, Belfast, Ireland 1965

University of Pittsburgh, 1965-1967

University of Colorado, 1967 - present

University College London, Mullard Space Science
Laboratory, 1970-1971

Gary E. Thomas

Associate Professor, Astro-Geophysics

Ph.D. University of Pittsburgh, 1963

Service d'Aeronomie, Meudon, France, 1962-1963

Research scientist, U. S. Army - Fort Monmouth, 1963-1965

Los Alamos Scientific Laboratory, Jan - Aug 1965

Aerospace Corp., El Segundo, California, 1965-1967

University of Colorado, 1967 - present

Visiting Faculty 1972 - 1973

- Howard McAllister - Professor of Physics and Astronomy, University of Hawaii
Ph.D. University of Colorado 1959
- Murray McEwan - Senior Lecturer of Chemistry, University of Canterbury, New Zealand
Ph.D. University of Canterbury 1965
C.R.E.S.S., Ontario, Canada 1965 - 1968
- H. Warren Moos - Professor of Physics, Johns Hopkins University
Ph.D. University of Michigan 1962
Stanford University 1961 - 1964
- Stanton Peale - Professor of Physics, University of California, Santa Barbara
Ph.D. Cornell University 1965
University of California, Los Angeles 1965 - 1968

Postdoctoral Research AssociatesRalph Bohlin

Ph.D. Princeton University 1969

Eric Chipman

Ph.D. Harvard University 1972

Benedict Domenico

Ph.D. University of Colorado 1972

H. Uwe Keller

Ph.D. University of Munich 1971

Michael MolnarPh.D. University of Wisconsin 1970
Goddard Space Flight Center 1970 - 1971Kevin Pang

Ph.D. University of California 1970

Helen PolandPh.D. Indiana University 1969
Visiting Member - JILA, 1969 - 1971Gary Rottman

Ph.D. Johns Hopkins University 1972

Steven Seitel

Ph.D. University of Montana 1972

Douglas StricklandPh.D. University of Pittsburgh 1968
Research Associate, University of Florida 1968 - 1970

Students Associated With LASP Projects

<u>Students</u>	<u>Degrees</u>	<u>Present Location</u>
R. B. Norton	1967 Ph.D.	Environmental Research Laboratory National Oceanic and Atmospheric Administration, Boulder, Colorado
R. M. Jones	1968 Ph.D.	Ionospheric Telecommunications Laboratory, Boulder, Colorado
P. E. Luft	1968 M.A.	Cryogenics Division of the National Bureau of Standards, Boulder, Colorado
J. B. Pearce	1968 Ph.D.	Ball Brothers Corporation, Boulder, Colorado
G. P. Anderson	1969 M.Sc.	Laboratory for Atmospheric and Space Physics, Boulder, Colorado
R. A. Jones	1969 Ph.D.	U. S. Army Foreign Science and Technology Center, Charlottesville, Virginia
J. M. Ajello	1970 Ph.D.	Jet Propulsion Laboratory, Pasadena, California
J. G. Anderson	1971 Ph.D.	University of Pittsburgh, Pittsburgh, Pennsylvania
L. G. Meira	1971 Ph.D.	Comissao Nacional de Atividades Espaciais, Sao Paulo, Brazil
W. E. Sharp	1971 Ph.D.	University of Michigan Ann Arbor, Michigan
D. E. Anderson	1972 M.Sc.	University of Colorado Boulder, Colorado
D. W. Rusch	1972 Ph.D.	University of Michigan Ann Arbor, Michigan

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